International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 1 Feb 2018, 1049-1058

EXPERIMENTAL STUDY OF MECHANICAL AND METALLURGICAL PROPERTIES OF FRICTION STIR WELDED DISSIMILAR ALUMINUM ALLOYS

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ABSTRACT

Friction stir welding is a comparatively quiet new solid state metal joining process developed by the Welding Institute in 1991 and is used for joining of aluminum alloys and dissimilar materials which were difficult to using conventional welding. Objective of this work is to produce sound weld of dissimilar aluminum alloy of AA7075 and AA6101 by using FSW process with two different tool pin profile and investigate the mechanical and metallurgical properties such as tensile Strength, impact strength and microstructure in terms of Process parameters such as tool Rotational speed, tool transverse speed and axial force. Better mechanical properties were obtained at a tool rotational speed of 1200 rpm, transverse speed 45mm/min and axial force of 6KN. Better mechanical and metallurgical properties were obtained by the joint made by straight cylindrical tool pin profile. This study was focused on process parameters and suitable tool profile that necessary for fabricating superior welded joints.

KEYWORDS: Friction Stir Welding, Dissimilar Aluminum Alloys, Mechanical Properties, Process Parameters & Tool Profile

Received: Nov 27, 2017; **Accepted**: Dec 16, 2017; **Published**: Feb 01, 2018; **Paper Id**.: IJMPERDFEB2018125

Original Article

INTRODUCTION

In Friction stir welding process, a rotating non consumable tool is to be penetrated into the butt surface of the weld plate and also it travels along the butting line for weld consolidation. The welding plates and tool arrangement of friction stir welding is as shown in figure 1. The tool profile and shoulder are supportive for sufficient heat and materials fraternization by stirring and fabricating the joint. Friction stir welding process cannot melt the joining edges and the heat induced inside by means of friction between the metal-tool edge and the soft distortion occurred [1].In friction stir welding, no shielding gas or flux is used, thereby making the process environmentally forthcoming and energy efficient. The joining does not involve any use of filler metal and therefore any aluminum alloy can be joined without concern for the compatibility of a masterpiece, which is an issue in fusion welding. In FSW there is no flux is used and do not have any filler metal so that the properties of the joints are improved comparatively to base metal [2].

In FSW, parameters play an important role like tool design, material, tool rotational speed. Welding speed and axial forces are required to produce effective friction stir welded joint and obtain the joint efficiency of 60%[3].In FSW joints are obtained by using various process parameters. An ANN model is developed using

MATLAB and optimization of processes parameters is carried out by comparing the result obtained by Design of experiments and experimental values of different tool pin profile with various process parameters the welding carried out on different materials AA6061, AA6351 and AA6082.[4]. A systematic approach to develop the mathematical model for predicting the ultimate strength, yield strength and percentage of elongation of AA6351 which is widely used in industries. They were found the increase in the rotational speed, welding speed and axial force leads to the increase in the ultimate strength and its reaches a maximum value and then decreases [5]. Effect of FSW process parameters on mechanical properties of welded AA6061 aluminum alloy. They were found that the tensile strength initially increased with the increase in tool rotation speed, welding speed and axial force, but tensile strength decreased after reaching a maximum value with the further increase of the these parameters [6]. Friction stir welding of very thin plates of the AA6016-T4 aluminum alloy, it was concluded that the difference in tool geometry and welding parameters included significance changes in the material flow path during welding as well as in the microstructure in the weld nugget [7].

Tensile strength of FSW aluminum alloy A319 has been evaluated under different processing conditions using 33 full factorial experimental design. Tool rotation speed has been found dominant parameter for tensile strength followed by welded speed, axial force shows minimal effect on tensile strength compared to other parameters. A nonlinear regression model, developed to correlate tensile strength, has been found to be useful in predicting tensile strength [8]. Five different tool pin profile with 3 different welding speed have been used to make the joints. It was found that the straight square pin profile with 63 mm/min produced better tensile strength than other profile and welding speed [9]. The FSW of the dissimilar aluminum alloy trial was carried using cylindrical tool profiles and testing the joint and compare the result with base materials [10]. Compare the mechanical and metallurgical properties of TIG, MIG and Friction stir welded joints dissimilar aluminum AA5083-0 and AA6061-T6 aluminum alloy influenced by welding process parameters and post weld aging treatment. FSW joints compared to MIG and TIG welded joints. Hence the FSW process exhibited superior mechanical and metallurgical properties [11]. The mechanical properties of the Dissimilar Friction stir welded specimens were tested and compared with the base materials and microstructures of a parent and a welded specimen through optical microscopy and it is observed that the weld parameters have a significant effect on mechanical and metallurgical properties of the weld [12].

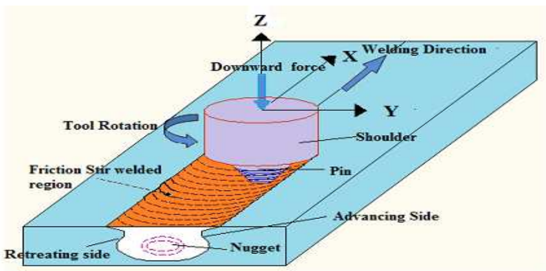

Figure 1: Schematic Diagram of Friction Stir Welding (Courtesy: S. Sattari [14])

In this study, the dissimilar aluminum alloy AA7075-T6 and AA6101 of 6 mm thick plates were welded by friction stir welding the following process parameters tool rotation speed (1000 rpm, 1100 rpm, 1200 rpm), axial force (4 kN, 5 kN, 6 kN), welding speed (30 mm/min, 45 mm/min, 60 mm/min) with help of straight cylindrical and taper cylindrical tool made up of mild steel hardened by flame hardening.

EXPERIMENTAL WORK

Materials and Methodology

The materials used for this study is rolled plate of AA7075-T6 and AA6101 aluminum alloy and chemical composition and mechanical properties of parent materials are tabulated in Table 1 and Table 2 respectively.AA7075-T6 plate was positioned in the retreating side and AA6101 plate was positioned in the advancing side. High strength aluminum alloy AA7075-T6 at the retreating side and by placing the aluminum alloy AA6101 at the advancing side. Since if the weaker alloy is located at the retreating side, the fabricated weld will become weaker than the weaker alloy is at the retreating side [13]. The rotating straight cylindrical and Taper cylinderical tool used in this study was made of high speed steel tool steel shown in figure 2.Using straight cylindrical tool trail experiments conducted to determine the working and possible range of process parameters. To choose a proper orthogonal array for experiments, the total degree of freedom has to be calculated. The degree of freedom are defined as the number of comparison between process parameters that need to be made to determine which level is better and specifically how much better it is. Three experiments in each set of process parameters have been performed on AA7075 and AA6101 plates by L9 orthogonal array. The three factors used in this experiment are the rotating speed, axial force and travel speed. The factors and the levels of the process parameters are presented in Table 3 and these parameters are taken based on the previous trials to weld the FSW of aluminum's [15].

Table 1: Chemical Composition (Wt%) of AA6101 and AA7075 Aluminum Alloy

Element	Al	Si	Fe	Cu	Mg	Mn	Zn	Ti	Cr
AA6101	95	0.8	0.7	0.4	1.2	0.15	0.25	0.15	0.35
AA7075	87	0.4	0.5	2.0	2.9	0.3	6.1	0.2	0.28

Table 2: Mechanical Properties of AA6101 and AA7075 Aluminum Alloy

Element	UTS (MPa)	YS (MPa)	% Elongation	Hardness
AA6101	135	118	19	48
AA7075	622	573	10	145

Figure 2: FSW Tool Profiles

FSW Process Parameters and Specimen Preparation

In FSW, first step in the selection of process parameters which is play the major role in determining the weld quality. The process parameters workable range for the experiments was chosen in order to control the dig formation at the middle of the retreating side may due to insufficient heat generation and metal transportation if the tool rotational speed is less than 1000 rpm and piping defect was observed at the top of retreating side may be due to excess turbulence caused by higher tool rotational speed of 1400 rpm. When the welding speed was less than 22mm/min, tunnel defects was observed at retreating side due to excess heat input per unit length of weld. When the welding speed higher than 75mm/min, dig formed at retreating side and middle of weld region was observed inadequate flow of material caused by insufficient heat

input. When axial force is less than 2KN, pin hole defect at retreating side was identified due to absence of vertical flow of materials caused by insufficient downward force. When the axial force was increased beyond 4KN, if resulted dig was formed at both sides[8]. In the present study, three process parameters such as tool rotational speed, welding speed, axial force were selected for this study shown in the Table 3. The parameters were kept constant and used to fabricate the dissimilar joints using FSW machine developed by R.V Machine Tool, Model No: SPM104, Coimbatore as shown in figure 3. A straight cylindrical tool with a tilt angle 1.5° probe was plunged to a predetermined depth at the interface of the butting surface of the plates to be welded. The tool is taken back after the weld is completed, leaving a hole at the end. The test specimen of size 100 mm length, 50mm width and 6mm thick are prepared from aluminum alloy AA7075-T6 and AA6101 rolled plates before and after weld as shown in figure 4. ASTM E8 guidelines were followed for preparing the tensile test specimens. Electromechanically controlled universal testing machine (Make: FIE, Model: UTN 40) was used to evaluate the tensile properties of the specimen. Charpy impact specimen was prepared with notch at weld centre. Impact test was carried out on a pendulum type impact testing machine at room temperature. The amount of energy absorbed is fracture was recorded.

Table 3: FSW Process Parameter and Tool Geometry

Sl.No	Process Parameters	Values
1	Tool Rotational Speed (rpm)	1000, 1100, 1200
2	Weld Speed(mm/min)	30, 45, 60
3	Axial Force (KN)	4, 5, 6
4	Tool Shoulder Diameter (mm)	18
5	Tool pin diameter (mm)	6
6	Tool pin length (mm)	5.7
7	Tool profile	Circular Straight and Circular Taper

Figure 3: Friction Stir Welding Specimen

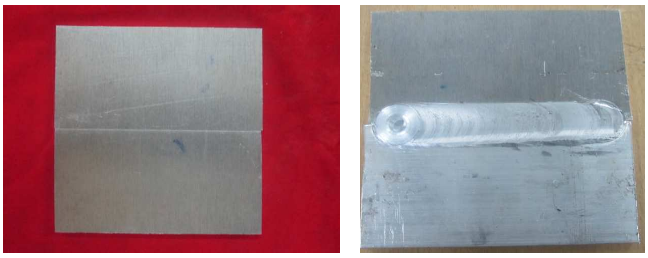

Figure 4: Friction Stir Welded Specimen

RESULTS AND DISCUSSIONS

Effect of Process Parameters on Tensile Strength

The tensile test specimens were extracted from each joint. These samples were tested using universal testing

machine as per the ASTM E8 guidelines and tested specimen shown in figure 5. The test carried out of different process parameters shown the Table 4 and Table 5 the tensile properties, various significantly with respect to process parameters. A higher tensile strength of 128.5 MPa was obtained in the joint made at tool rotational speed of 1200 rpm, axial force of 6KN and welding speed of 45mm/min. The lower tensile strength was attained in the joint made at tool rotational speed of 1000 rpm, axial force of 4KN and welding speed of 30mm/min shown in figure 6. Generally the tensile strength is poor at lower rotational speeds like 800 rpm, due to insufficient tool string action and low heat generation [16]. Therefore the tool rotational speed of 1000 rpm and axial force of 4KN for both maximum and minimum tensile strength was obtained. Hence the Tool rotational speed followed by welding speed, dominate the tensile strength when using straight cylindrical tools. The taper cylindrical tool's tensile strength was found to be low compared to straight tool due to insufficient heat generation and mixing of both metals.

Table 4: FSW Process Parameters with Tensile Strength

Sample	Tool Rotational Speed (rpm)	Axial Force (KN)	Welding Speed (mm/min)	Tensile Strength (MPa)	
				Circular Straight Tool	Circular Taper Tool
1	1000	4	30	116.13	111.93
2	1000	5	45	120.18	116.25
3	1000	6	60	124.32	118.28
4	1100	4	45	125.37	111.93
5	1100	5	60	122.93	114.1
6	1100	6	30	119.24	114.67
7	1200	4	60	124.54	113.92
8	1200	5	30	125.1	114.78
9	1200	6	45	128.5	120.54

Figure 5: Tensile Tested Specimens

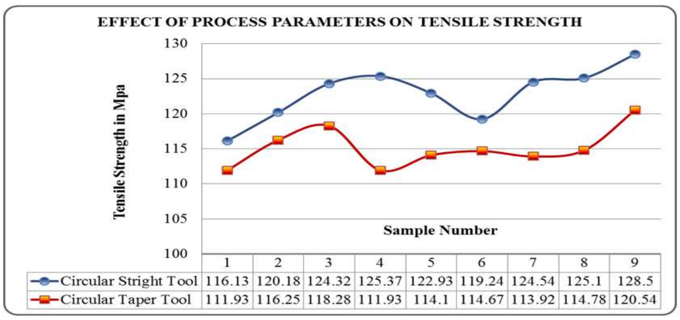

Figure 6: Effect of Process Parameters on Tensile Strength

Effect of Process Parameters on Impact Strength

Figure 7: Impact Tested Specimens

The impact test specimens were extracted from each joint. These samples were tested using pendulum type impact testing machine as per the ASTM guidelines and tested specimen shown in figure 7. The test carried out for different process parameters shown in the Table V the impact strength varies significantly with respect to process parameters. Higher impact strength of 22 Joules was obtained in the joint made at tool rotational speed of 1100 rpm, axial force of 5KN and welding speed of 60mm/min. The lower impact strength was attained in the joint made at tool rotational speed of 1200 rpm, axial force of 6KN and welding speed of 45 mm/min showed in figure 8. The impact strength decreases with an increase in the tool rotational speed. In fact, tool rotational speed increases more heat, due to the lower cooling rate coarse grain structure formed, so the impact strength is decreased. Hence, from the Table 5, axial force dominated the impact strength which is followed by the welding speed.

Table 5: FSW Process Param Eters with Impact Strength

Sample	Tool Rotational Speed (rpm)	Axial Force (KN)	Welding Speed (mm/min)	Impact Strength (J)	
				Circular Straight Tool	Circular Taper Tool
1	1000	4	30	18	14
2	1100	5	45	12	32
3	1200	6	60	16	24
4	1000	4	45	20	22
5	1100	5	60	22	16
6	1200	6	30	18	20
7	1000	4	60	20	20
8	1100	5	30	14	20
9	1200	6	45	10	20

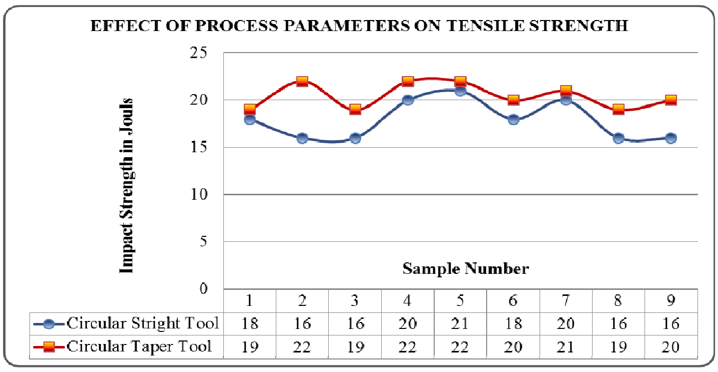

Figure 8: Effect of Process Parameters on Impact Strength

EFFECT OF PROCESS PARAMETERS ON HARDNESS AT WELD ZONE

The test specimens were extracted from each joint. These samples were tested using vickers hardness testing machine as per the ASTM guidelines. The test carried out of different process parameters shown the Table VI the hardness value varies significantly with respect to process parameters at the following locations 1. Base material, 2. Thermo-mechanically affected zone and 3. Heat affected zone shown in figure 9. Higher VHN of 153.92 was obtained in the joint made at tool rotational speed of 1100 rpm, axial force of 5 KN and welding speed of 60mm/min due to highest welding speed in sufficient cooling time.

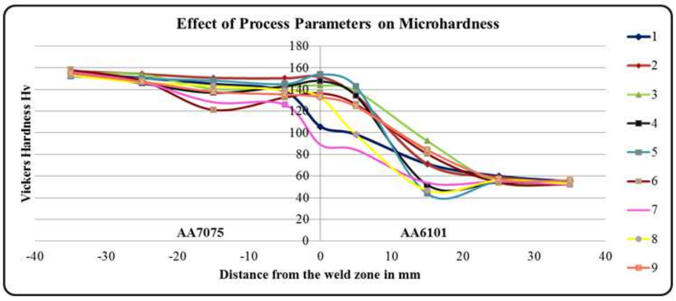

Figure 9: Microhardness Measurement Locations

EFFECT OF PROCESS PARAMETERS ON MICROSTRUCTURE AT WELD ZONE

Two different tool pin profiles were used in this study along with process parameters. The required size of microstructure specimen extracted from the weld zone of welded joints. The specimens were polished by using various grade emery sheets. Optical micrographs of base metal and weld zone of friction stir weld specimens shown in Figure 10. The grain shapes and its flow orientation in the heat affected zone of straight, circular tool pin profile were analyzed by optical microscope range of 500X. The microstructure of weld zone consists of equalized grains and Fe3SiAl12 and Mg2Si particles distributed in a matrix of aluminum solid solution throughout the structure. Also onion ring was found in the weld zone at 1000 rpm. Compared to the base material, both metals are mixed effectively at 1200rpm. This is possible due to the generation of the sufficient heat supplied by the high rotational speed (1200 rpm) and rapid solidification of the grains at the medium welding speed (45mm/min) which is evident from the micrograph images shown in the Figure.10

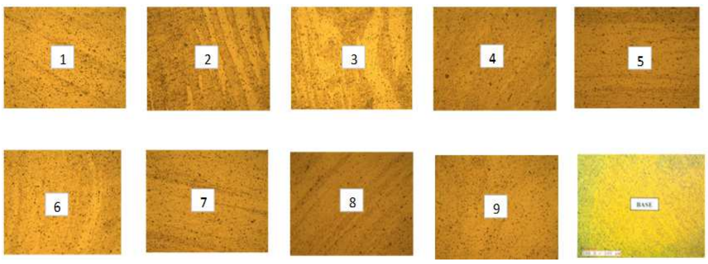

Figure 10: Microstructure of Joints at Weld Zone (Circular Straight Tool)

Figure 11 shows the micrograph of the produced weld after throughly etched with the Keller's reagent marked as nuggest zone and base metal. Taper circular tool pin profile and welding parameters, the microstructural analysis was examined in the stir zone of welded blank in the transverse section As like macrostructure of straight circular pin profile, the formation of onion ring was not observed in the weld region. The micrograph analysis clearly reveals us that insufficient frictional heat was generated during the circular taper tool used.

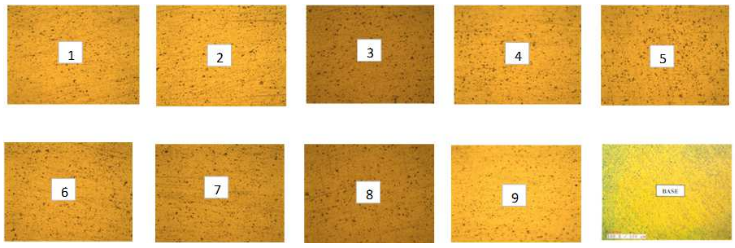

Figure 11: Microstructure of Joints at Weld Zone (Circular Taper Tool)

CONCLUSIONS

The role of welding parameters on the mechanical properties such as tensile strength, impact strength and hardness of friction stir welded AA7075-T6 and AA6101 were investigated. The following conclusions are made.The tensile strength, impact strength of friction stir welded plate decrease compared to the parent metal and it is observed at the heat affected zone.

- A higher tensile strength of 128.5 MPa was obtained in the joint made at tool rotational speed of 1200 rpm, axial force of 4KN and welding speed of 45 mm/min with straight cylindrical tool profile. Higher impact strength of 22 Joules was obtained in the joint made at tool rotational speed of 1100 rpm, axial force of 5KN and welding speed of 60mm/min. Higher VHN of 153.92 was obtained in the weld zone made at tool rotational speed of 1100 rpm, axial force of 6KN and welding speed of 60mm/min..
- Tensile strength increased with an increase in tool rotational speed and decreased with an increase in axial force. Thus Tool rotational speed and Welding speed are the influences of tensile strength.
- Impact strength decreased with an increase in rotational speed and increased with an increase in axial force followed by welding speed. Thus, the axial force influences impact strength.
- Effective mixing of material and fine grained structure was found by using Straight cylinderal tool profile.
- Better Mechanical and Metallurgical properties were found in the joint made by Straight cylindrical tool profile
- Wide-range of experimentation is required to study the effect of process parameters on properties of dissimilar aluminum AA7075-T6 to AA6101-T6 friction stir welded specimen with different tool pin profile.

ACKNOWLEDGEMENTS

The authors are grateful to Annamalai University for providing to carry out fabrication of friction stir welded joints**.**

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